LEARNABILITY OF LARYNGEAL ABDUCTION IN VOICELESS FRICATIVES: CROSS-LINGUISTIC EVIDENCE

Olga B. Gordeeva

Acapela Group, Mons (Belgium) and SSRC, Queen Margaret University, Edinburgh (UK)
ogordeeva@gmail.com

ABSTRACT

Previous research of laryngeal-oral gestural co-ordination in vowel-voiceless fricative sequences (Vf) shows that earlier timing of glottal opening relative to oral constriction is a *language-independent* aerodynamic property. In this paper, we provide evidence that the extent of this gestural dissociation is nonetheless *learnable* in a *variety-specific* way, and is, thus, actively controlled. This study shows that in some British English varieties, large temporal laryngeal-oral dissociation in Vf transitions is a correlate of the fricative /voice/ contrast, while the dissociation is much tighter in a language neutralising /voice/ such as Russian. The learnability of Vf-gestures is important in the context of theories on gestural phonology and acoustic multidimensionality of the /voice/ contrast.

Keywords: aspiration, fricatives, laryngeal abduction, voice.

1. INTRODUCTION

It is known that /-voice/ fricatives are produced with a wide opening of vocal folds and that the glottal abduction is typically initiated prior to the onset of oral constriction [1]. Consequently, vowels before /-voice/ fricatives show signs of the earlier glottal abduction and increasing transitional aspiration. This effect has been observed cross-linguistically in the languages such as Swedish, Italian and German [2]. Therefore, it has been hypothesised that earlier glottal abduction and the presence of aspiration in vowel-voiceless fricative transitions is a universal characteristic [2].

So far there is only limited evidence of learnability (i.e. active control) of such laryngeal-oral dissociation in voiceless fricative production. The lack of evidence contrasts with the extensive literature on language-specific glottalisation or preaspiration associated word-final /-voice/ stops, or word-initial voice-onset time (VOT) in stops. Learnability of Vf-gestures is important in the context of complex gestural coordination in obstruents and acoustic multidimensionality of the /voice/ contrast [3]; as well as has implications in the contexts of language acquisition.

While aerodynamic consequences of maintaining sufficient airflow for frication noise explain the early glottal abduction relative to oral constriction in voiceless fricatives, there are also reasons to assume that the extent of this dissociation can be learnable.

For example, studies of the Middlesbrough variety of British English [4] and of Scottish Standard English (SSE) spoken in the Scottish Central Belt [5] report on 'preaspirated' voiceless fricatives to the extent as large as known for stops. Although variably present/absent in different SSE speakers, open vowels like in "bus" can have low amplitude aspirated Vf-transitions that are as long as the vowel itself. In contrast, there is a general lack of reports on preaspirated fricatives for other languages. This suggests that fricative preaspiration might be a variety-specific characteristic.

Variety-specific linguistic functioning can be seen as a sign of learnability/phonologisation. It has been shown for SSE [5] that variable aspiration in Vf-transitions, as in [bʌ^{h}s] "bus" versus [bʌz̥] "buzz", helps maintaining the /±voice/ contrast phrase-finally [5]: i.e. in the context where the importance of phonetic voicing is demoted. However, aerodynamic explanations may imply that speakers of any language should produce preaspirated Vf transitions as in SSE.

In this paper, we aim to provide direct evidence on the learnability of laryngeal-oral dissociation of vowel-fricative transitions from *a cross-linguistic angle.* If different languages (or varieties) use a sufficiently different extent of aspiration in vowel-/±voice/ fricative transitions (in close vowels less prone to such effects [5]), this should be seen as an argument in favour of its learnability rather than (just) automatic universality for aerodynamic reasons.

2. METHOD

2.1. Languages/varieties

For the cross-linguistic comparison, we chose Scottish Standard English (SSE) as preaspirated fricatives have been reported in this variety [5]. Southern Standard British English (SSBE) is chosen as it is a variety closely related to SSE, yet no reports of preaspirated fricatives have been made so far. Modern Standard Russian (MSR) is informative, since (unlike the English varieties) the /voice/ contrast may be neutralised: i.e. in some contexts (e.g. phrase-finally) the neutralisation can be obligatory and categorical, while in others it is phonetically gradient [6]. For the British English varieties, it seems reasonable to assume that the neutralisation of word-final obstruents like /z/ is not complete, and is phonetically gradual [3].

2.2. Subjects

Data were gathered from MSR (N=5), SSE (N=5) and SSBE (N=4) female middle class speakers aged between 25 and 45 years old. All speakers were recruited in Edinburgh, Scotland.

2.3. Materials

The data included target words with consonant-vowel-fricative structure with varied fricative /±voice/ conditions (see Table 1). The targets were embedded in two carrier sentences in four phrasal positions: i.e., phrase-initial, -medial and two phrase-final positions. The carriers and the targets were cross-linguistically matched for rhythmical and syllabic structure. The consonantal /±voice/ and place of articulation was matched across the languages. The front/back variability in close rounded vowels in the cross-linguistic targets had no relevant effect on the chosen acoustic measures. Each speaker repeated the carrier phrases five times per target. The resulting set contained 40 instances per speaker, and a total of 560 instances for all 14 speakers.

Table 1: Carrier sentences used in the Russian and English recording sets.

	English	Russian
Carrier	That's a *goose*.	Ehto *gus*'.
	A *goose* is a *goose*, and nothing but a *goose*.	Tot *gus'* – ehto *gus'* i tol'ko tot *gus'*.
Targets		
-voice	“goose”	“gusj”
+voice	“choose”	“tuz”

The subjects were recorded in a sound-treated booth using a condenser boundary microphone. The recording volume settings were kept constant. The subjects were given no specific instructions about the phrasal accent placement in the utterances.

2.4. Analyses

2.4.1. Annotation

The recordings were digitised at a sampling rate of 11050 Hz and 16-bit quantisation. All annotations were performed using PRAAT [7].

For each token, the syllable prominence was analyzed and labeled. Only syllables produced with a phrasal accent (N=458) were considered for further analyses. Vowel and consonantal duration was measured after visual inspection of the waveform and the spectrogram of each instance.

2.4.2. Acoustic Analyses

For the analysis, we chose a set of acoustic correlates inferring wide glottal abduction (zero-crossing rate throughout the second vowel part) and the timing of laryngeal-oral dissociation in the Vf transition (voicing offset ratio). The acoustic measures were automatically derived in PRAAT based on manual annotations of segment duration.

Voicing offset ratio (VoiceOff, %) is a measure of timing of voicing offset in Vf sequences relative to the fricative onset. Traditional measures of voicing offset involve the fricative scope only [e.g. 3;8]. The measure used here traces the timing of voicing offset *prior* to the onset of oral fricative stricture, while it normalises for the differences in absolute segmental durations (V or f). The voicing offset values are calculated between the timing of fricative onset (0 %) and the fricative offset (-100%), or between the timing of fricative onset (0%) and vowel onset (100%). The negative values indicate the voicing offset in the fricative, while positive values indicate the offset in the vowel.

The phonetic voicing was derived from speech waveforms using the cross-correlation algorithm with 75 Hz and 400 Hz as minima and maxima derived from the pitch extremes in the datasets.

Zero-crossing rate (ZCR, per sec) is an acoustic correlate of mid- and high frequency aspiration in the spectrum. The noise in these frequencies is found to be a more important perceptual cue to aspiration/breathiness than that contained in lower frequency spectral components [9;10]. ZCR is calculated in the time-domain of a waveform as the number of zero-crossings of the wave (per sec) divided by the number of samples. ZCR tends to be the highest for voiceless fricatives. Unlike periodicity-dependent spectral tilt or open quotient. ZCR is a measure appropriate for either voiced or voiceless stretches of aspiration.

In aspirated speech, dominant low frequency (H1) components can cause quasi-sinusoidal displacing the wave from the zero-line [11] and making it impossible to use the technique to measure aspiration-caused aperiodicity. To normalise for this undesired effect, waveforms were band-pass filtered with an upper limit at 5.5 kHz and a flexible lower limit defined at 1.5*maximum pitch in for each vowel token. Mean ZCR was measured in three parts of the vowel: ZCR_mid (3/5th part), ZCR_4/5 (4/5th part), ZCR_final (5/5th part). Additionally, the ZCR_change measure: i.e. the difference between the final compared to the middle V part, reflects aspiration increase in the second part of the vowel.

2.4.3. Statistical Analyses

In order to test the cross-linguistic learnability of laryngeal-oral dissociation in oral /±voice/ fricatives, we ran multivariate analysis of variance (α = .05) with the acoustic correlates of aspiration: VoiceOff, ZCR_mid, ZCR_4/5, ZCR_final, ZCR_change as the dependent variables and with LANGUAGE (SSE, SSBE and Russian) and fricative VOICE (-voice, +voice) as fixed factors.

3. RESULTS

The results are presented in Table 2. There was a highly significant main effect of LANGUAGE and a highly significant interaction between the factors LANGUAGE and VOICE on all acoustic measures of glottal abduction in Vf-sequences (except for ZCR in mid-vowel). Both results confirm our hypothesis that the speakers of Russian and of two British English varieties (SSE and SSBE) produce *different* patterns of aspiration in vowel-fricative sequences suggesting its *language-specific* implementation.

Additionally, there was also a highly significant main effect of VOICE on all the dependent variables (except for mid-vowel ZCR) suggesting a non-neutralising nature of the /voice/ contrast in the languages considered.

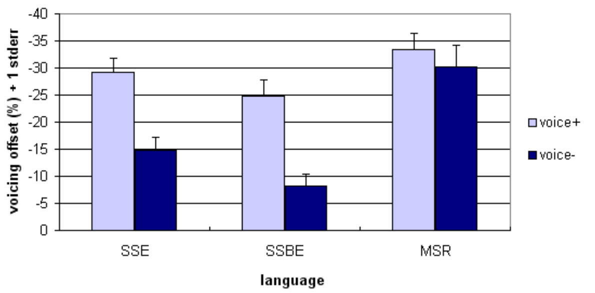
Tukey HSD posthoc tests for the factor LANGUAGE show that Russian was significantly different (p<.05) from both SSE and SSBE for the set of ZCR-measures, while the two British English varieties were not significantly different from each other. Russian and SSE were both significantly (p<.05) different from SSBE for the VoiceOff measure.

Table 2: The results of the multivariate ANOVA.

	Main effects				Interaction	
	Language (L) (df=2,452)		Voice (V) (df=1,452)		L*V (df=2,452)	
Variables	F	P	F	P	F	P
VoiceOff	14.4	<.001	24.3	<.001	3.0	<.05
ZCRmid	11.0	<.001	3.3	Ns	2.1	ns
ZCR_4/5	10.9	<.001	7.5	<.001	5.4	<.01
ZCRfinal	14.3	<.001	42.0	<.001	4.0	<.001
ZCR change	9.7	<.001	63.2	<.001	5.3	<.001

The results for the voicing offset ratio are presented in Fig. 1. The figure shows that SSE, SSBE and Russian speakers equally make a distinction between word-final /±voice/ fricatives in terms of the timing of phonetic voicing. Although the /±voice/ differences are much smaller (and more neutralising) for Russian, supporting previous reports [6]. The differences in VoiceOff are not *fully* neutralising, so that the /voice/ contrast is still marginally maintained by the Russian speakers across the prosodic contexts considered.

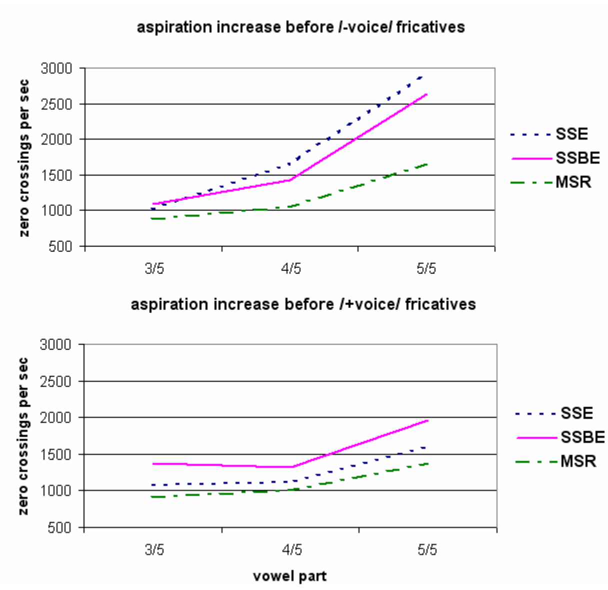
Figure 1: Language means (+ 1 standard error) in voicing offset ratio (%) in vowel-fricative transitions as a function of fricative /voice/**.**



The most important result of this study is that the high frequency aspiration present in the Vf-transitions in SSE and SSBE is significantly different (p<.05) from the pattern in Russian. The crosslinguistic differences are shown in Fig. 2 visualising the changes in higher frequency aspiration throughout the second vowel part (ZCR in the 3/5th, 4/5th and 5/5th parts) in voiceless (upper pane) versus voiced fricatives (lower pane).

The result shows that the SSE and SSBE speakers cluster together in increasing aspiration noise before voiceless fricatives (upper pane) already in the 4/5th and more so in the 5/5th part of the vowel. The increase is significantly smaller in Russian suggesting a tighter in timing laryngeal-oral dissociation of gestures compared to the two British English varieties (SSE and SSBE). Between SSE and SSBE, the aspiration increase is the biggest for the Scottish speakers confirming [5], although substantial aspiration in SSBE is a new finding.

Figure 2: Language means in zero-crossing rates traced through the second vowel part (3/5th, 4/5th, 5/5th) with the upper pane representing vowel-voiceless fricatives, and the lower pane vowel-voiced fricative transitions.



4. DISCUSSION AND CONCLUSIONS

The aim of this study was to provide some cross-linguistic evidence on learnability of laryngeal-oral dissociation in the production of word-final voiceless fricatives. The analyses included measures of aspiration in Vf-transitions against voiced fricatives as a baseline. The cross-linguistic differences in the amount of aspiration in higher frequency between SSE and SSBE on one hand versus Russian on the other support the findings in [5] that laryngeal-oral dissociation is part of *variety-specific* phonological implementation of voiceless fricatives, and that some British English varieties are prone to these effects [4;5]. The fact that the transitional aspiration is manifested in close vowels (less prone to preaspiration see discussion in [5]), suggests that both English varieties may permit preaspirated voiceless fricatives as pronunciation variants in more open vowels.

The results further show that the phonetic variants known in British English varieties (like [buʰs] or [streʰs]) produced with a high amount of transitional aspiration might be less spread in languages like Russian with a more tightly timed laryngeal-oral gestures in word-final fricatives. This result parallels the learnable glottal patterns observed in word-final stops such as variety-specific glottalisation or preaspiration [12]; and, therefore, simplifies models of word-final obstruent production.

A language-specific phonologisation is possibly mediated by the relative (and language-independent) ease with which the laryngeal and oral stricture gestures are dissociated before voiceless fricatives [2], since both aspiration and oral frication require large-in-amplitude glottal opening [1].

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